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Original research article

The afterlives of solar power: Waste and repair off the grid in Kenya

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ABSTRACT

One neglected socio-cultural and political dimension to the rapid diffusion of solar power in Sub-Saharan Africa is the question of what happens when things fall apart. Investors in the small-scale renewable energy sector are increasingly concerned with the status of broken or non-functioning products and there is an emerging consensus around the need for centralised recycling systems as the solution to future flows of 'solar waste'.

But what does the afterlife of off-grid solar products look like from below? Grounded in anthropology, geography and economic sociology, this paper tracks the impact of off grid solar products through contexts of breakdown, repair, and disposal. Combining stakeholder interviews, a longitudinal survey of product failure rates in Kenya and ethnographic research at a repair workshop in the town of Bomet, we challenge narratives of energy transitions that fail to address the environmental consequences of mass consumption and present an alternative approach to solar waste embedded in cultures and economies of repair.

1. Solar things fall apart

'Any solar product is just like a big microchip, with many of the same components, materials and problems,' Sheila Davis, director of the Silicon Valley Toxics Coalition, told a workshop on solar waste at the Strathmore Energy Research Centre in Nairobi in 2015. 'If micro-electronic technology can't be recycled or repaired it is designed for the dump. Unless we think about these things now solar technology will end up in the same place.'

One neglected socio-cultural or political dimension to the rapid diffusion of solar power for domestic use in Sub-Saharan Africa over the past decade is the question of what happens to small-scale solar technologies when they break down. As the expansion of access to solar energy has become an important part of responses to energy poverty, precariousness and vulnerability, it has been easy to forget that solar photovoltaic technologies use similar constituent materials to those of almost any other electronic product or that solar panels and batteries contain materials that can have environmental and health impacts after use.¹

Investors in the off-grid solar industry celebrate increased domestic access to photovoltaics as a net win for people living in chronic energy poverty (e.g. [1]). But is it possible that, in an industry committed to growth, the user and the environment may also lose out, or that accelerated transitions to decentralised energy provision via solar

photovoltaics may also signal a point of no return for an e-waste burden across the Global South?

Sales figures offer some illustration of the potential scale of future electronic and electrical waste flows. Global sales of off grid solar devices reached 130 million between 2010 and 2017 [2]. Assuming half of these devices are discarded after 3–4 years, current estimates suggest that up to 26.2 million off grid solar devices could be out of use by 2017 [2, p. 175]. Such numbers suggest that the material politics of 'solar waste' needs to become part of the discussion about clean energy transitions in Sub Saharan Africa. The problem, we argue in this paper, drawing from research traditions in social anthropology, geography and sociology is no longer that *no-one* is talking about solar waste. The problem today is *how* solar waste is discussed, in what terms, and by whom.

Over the past five years questions about the sustainability and environmental impact of off grid solar energy systems and technologies have attracted increased attention from investors and bilateral donor agencies. In 2016, the UK's Department for International Development (DFID) commissioned a multi-country study to research electronic waste in 'Africa's off-grid renewable energy sector' [3]. The report concluded that the off-grid solar sector across 14 Sub Saharan African countries would produce 3600 t of electronic waste in 2017. Whilst this represented a fractional percentage of total estimated electronic waste flows it also put waste from off grid solar products on a par with

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¹ Achieving the Global Transition to Energy Efficient Lighting Toolkit UNEP (2012) http://www.learning.enlighten-initiative.org/ebook/en_lighten_english_complete.pdf

electronic waste from the mobile phone industry.² In response, the authors laid out a comprehensive pathway for action, focused on centralised take back, collection and recycling schemes.

The term ‘solar waste’ is problematic. As an umbrella term for a distinct sub-category within the larger, more established category of waste electrical and electronic equipment (known by the acronym WEEE) it can help to distinguish the responsibilities of key stakeholders, including manufacturers, producers, and trade associations, and to catalyse future action (from research to policy). But it also amalgamates into a single, apparently uniform category a diverse range of materials, component parts, metals and plastics.

When solar things break down they do not follow a single trajectory into electronic waste flows. Understanding what happens to off grid solar products at a moment of failure or breakdown requires us to consider solar waste in terms other than pure tonnage or potential financial value. Following broken things and their component parts as they move through homes, repair centres and office workshops offers an opportunity to see how material things accrue different values and meanings as they circulate [4,5]. Such an approach allows us to consider the ‘afterlives’ [6,61] of off grid solar products rather than focusing on what product designers and waste managers call the ‘end-of-life’.

Our paper begins, in section one, by putting recent debates around energy justice into the context of debates about the ‘end-of-life’ of electronic equipment. We highlight the ways that a persistent framing of sub-Saharan Africa’s energy transitions around narrowly defined goals of distributive justice (who has access) have neglected procedural justice (who determines the form and nature of that access). As we show, dominant justice framings have established the social and environmental costs of waste disposal as a ‘market externality’, diluting the responsibility of key actors and stakeholders. The terms of current debate about the management of solar waste presents new impetus for discussions of justice in renewable energy markets.

In section two we focus on the DFID-funded report and context in which it was commissioned. As we show, an emerging consensus around ‘solar waste’ rests on assumptions that both underestimate waste flows and volumes, and risk disrupting established economies of repair and re-use. Drawing on the emerging field of ‘discard studies’ we demonstrate the varied and productive range of activity that occurs around broken products, keeping materials in circulation long after breakdown, particularly in the Global South. Research on solar waste, we argue, must go to these other sites and not immediately ‘to the dump’.

In section three we examine practices and relationships around solar repair and waste in rural Kenya. As the biggest market for off grid solar products in Africa Kenya is a crucial location from which to consider and engage with such questions. In 2016, alone, 8.07 million off-grid solar systems were sold around the world, 3.83 million of them in Sub-Saharan Africa [7,8]. Out of this, an estimated 32% of all solar equipment sold in sub-Saharan Africa, or 2.1 million devices, were sold in Kenya [7,8].

Like other scholars have done with fruit or furniture (e.g. [9,64]) we follow solar things from the point they stop working as designed into homes and repair clinics where apparently dead things are given new lives or are reborn. We combine the results of a longitudinal survey with interviews with users, manufacturers, and distributors and ethnographic fieldwork at a repair clinic in the town of Bomet as well as company workshops across Nairobi. This research on solar repair points to the importance of a whole sphere of technical and economic activity that is not fully acknowledged in current approaches to waste, and

brings to the foreground the perspective and practices of users, repairmen and technicians.

In conclusion, we question the emerging consensus on solar waste management in sub-Saharan Africa. We challenge the treatment of broken off grid solar products simply and straightforwardly as an electronic and electrical waste problem, and the emerging consensus on recycling as the primary solution. Instead, we argue that decentralised waste management strategies focused on re-use repair and product design present alternative means of reducing waste. Such insights provide considerable opportunities for the off grid solar industry to shape more sustainable transitions.

2. Not just distribution: energy justice beyond the lifetimes of electronic things

Attempts to drive low-carbon energy transitions are crucially about justice. But when people and institutions invoke notions of ‘energy justice’ they do so in specific ways, establishing the parameters of what justice looks like and how it may be achieved [10–12]. Nowhere, perhaps, is this more evident than across the network of organisations that comprise Sub Saharan Africa’s off-grid solar industry.

In 2018 Sub Saharan Africa’s off-grid solar industry included small, medium, and large enterprises involved in the manufacturing and distribution of off-grid solar products, at least two international membership based trade associations, as well as the bilateral development organisations, UN agencies, international financial institutions, charities, and social investment funds. Across this network, organisational policies, programmes and priorities share a common commitment to the UN’s Sustainable Development Goal of access to clean, efficient, modern energy for all. They also share a common redistributive frame.

The UN’s Sustainable Energy for All Initiative, the World Bank/International Finance Corporation’s Lighting Africa programme, and DFID’s Energy Africa programme, for example, are all formulated as redistributive responses to the unequal or uneven distribution of access to affordable, efficient, energy deemed essential for artificial lighting, clean cooking, and telecommunications. For-profit solar energy start-ups like d.light design and Greenlight Planet present themselves in similar ways, as redistributive actors, readdressing the distribution of access to energy technologies, infrastructures, and services through products imbued with an ethic of care [13,14].

These framings of a distributional justice ‘deficit’ identify common causes and have important effects. Across the off grid solar industry the unequal distribution of modern energy is presented as the outcome of a historic mismanagement of public resources and public infrastructures; the outcome of a chronic misalignment between the interests of bureaucratic or political elites and the needs or vulnerabilities of the poor; and the outcome of national policies that have imposed barriers or impediments to the frictionless growth of markets.

Framed in this way the market emerges as the only plausible primary mechanism for realising energy justice, and the work of organisations coheres around the strengthening of market ecosystems. Steps to this endpoint demand the rapid expansion or acceleration of distribution systems and logics. In this frame, the key measure of energy justice is who has access to solar products and what they do with them at the point of use or the moment of consumption; hence, perhaps, the proliferation of social impact assessment tools and methodologies focused on health, education and livelihoods.

Yet such a tightly delimited framing of justice is far from addressing the full distribution of harms and risks across an energy system. The acceleration of markets for off-grid solar might address the uneven distribution of energy services but what of the distribution of risks and harms across supply chains, and through product lifetimes? From the first experimental installations of solar photovoltaics in the 1980s until the early 2000s solar entrepreneurs in Kenya and their businesses were environmentalists committed to the local sourcing of parts, their local manufacture, their local assembly and the technical training of

² In 2014 waste from solar equipment in 14 Sub Saharan African countries constituted approximately 800 t of a total, estimated 460,000 t of electrical and electronic waste, the report showed [3: p. ii]. This share was expected to increase to 0.5% of total e-waste volumes by 2017, similar in weight to electronic waste from mobile phones over the same period [3: p. 27].

employees to provide maintenance and repair services.³ Today however, dominant framings of ‘energy justice’ in the off-grid energy industry keep broader questions of local skills, system maintenance, product longevity, and the environmental impacts of mass consumption out of view.

As civil society organisations like the Silicon Valley Toxics Coalition (SVTC) as well as an increasing number social scientists remind us (e.g. [15]), there is nothing inherently ‘clean’ about clean technologies. On the contrary, the coupling of low-carbon innovation with the search for new sites of accumulation is producing new forms of social and environmental injustice [16]. Current framings of distributive justice in the off grid solar industry fail to address the politics of work and labour across sites of mining, sourcing, assembly, and manufacturing [17,18]. Meanwhile, the addition of batteries, broken circuit boards, plastic casings and photovoltaic modules to electronic waste flows pose new questions about whether or how the task of disposal will disproportionately distribute risk.

Increasing scrutiny of alternative energy projects and infrastructures have begun to reveal the reproduction and reformulation of historic power relationships in low carbon transitions. These range from attention to process of land acquisition around biofuels [19] and wind power [20], to the political economy of energy transitions across Sub Saharan Africa [21–24,60,62] and the impact of investments from the ‘rising powers’, India and China, in Africa’s regional energy systems [25]. To date, however, the justice implications of global supply chains for renewable energy technologies, and the relations of production and consumption that are being created by the growth of markets for off-grid energy technologies have remained critically unexamined. Whole systems approaches to energy justice have failed to engage with models and paradigms in business and management studies, as Hiteva and Sovacool [26] argue. Just as critically, we would argue, whole systems approaches to energy justice have yet to fully and empirically address actually existing renewable energy products and technologies across global supply chains and product life cycles.

A modest corrective to this imbalance can be achieved by bringing debates about energy justice into the off-grid solar industry, addressing questions of distributive justice across the lifetime of products and technologies. This is an approach that is rooted not just in scholarship on energy justice but also in the traditions of critical geography and cultural anthropology that foreground questions of work and labour, the circulation of material things in time and space, and the politics of mass consumption [27,16,28,29]. Rethinking the ‘afterlives’ of off grid solar products’ offers one entry point for engaging with the material politics of energy justice. If plastics and micro-electronic materials are going to outlast current business models, funding cycles and research projects by hundreds of years, surely our conceptualisation of renewable energy transitions in Sub-Saharan Africa must also shift temporal scale to accommodate them?

3. Discard studies and the off grid solar industry

The Global Off Grid Lighting Association (GOGLA) was formed in 2012 as a not-for-profit industry body representing the interests of solar powered lighting companies selling products in Sub Saharan Africa and South Asia. One of the association’s first acts was to publicly acknowledge the off-grid solar industry’s potential contribution to wider electronic and electrical waste flows. In 2013, at an international solar industry conference held in a Munich, Germany, the newly formed trade association convened an all-day meeting to discuss recycling. The meeting was attended by solar manufacturers, distributors, development partners as well as general electronic and electrical manufacturers, Hewlett Packard and Nokia. Participants discussed the barriers to establishing waste collection programmes for the sector, the

technical aspects of recycling photovoltaics and the commercial viability of recycling in Kenya, which was then, as now, Sub-Saharan Africa’s leading solar market.

The following year GOGLA members formally adopted a sector wide position on lifecycle and recycling [30].⁴ Soon after, GOGLA established a working group to examine ‘sustainability’ in the industry, and commissioned country reports from Kenya and Camaroon.⁵ In the same year the UK’s Economic and Social Research Council and the UK Charity Solar Aid co-funded a doctoral research project at the University of Edinburgh on what we called ‘solar waste’ [31]. Increasing attention to challenges of waste and recycling in Europe, however, was not immediately translated into knowledge or practice in East Africa.

In 2015 we organised a workshop on solar waste in Kenya [32]. The workshop took place against the backdrop of new e-waste management regulations drafted by the Government of Kenya’s National Environmental Management Authority, which aimed to provide a legal and institutional framework for handling and recycling electronic waste. The event brought together researchers and practitioners from across the off grid solar sector. For some participants, the sector’s ability to address electronic solar waste was hampered by a lack of public recognition and by a kind of ‘greenwashing’.

‘When people hear about e-waste, people are thinking about computers, people are thinking about mobile phones, no-one is thinking about solar’, Serah Nderitu, Research and Policy Officer at the Climate Innovation Centre, Nairobi, told us [32]. ‘Because we think solar is green, no-one is talking about, can I say, the dark side of solar...When you talk to a solar entrepreneur, they will be talking about financing, or how they can overcome the barriers to the market, no one is talking about waste.’ Meanwhile, prominent distributors of solar devices had begun to recognise the challenges presented by waste disposal but had yet to see any systematic action. As Jeremiah Ng’ayu Ngari, Solar Sales Manager for Total, Kenya put it during the same event, ‘A lot of companies haven’t had the waste component figured out. Then later, and almost as a side effect, they say, ‘Oh my gosh, we’ve got waste piling up what do we do with this?’

Shifts in the terms of debate came to a head at GOGLA’s 2015 conference, held in Dubai. Plenary speakers and panel presentations directly addressed the challenges of e-waste across the off grid solar industry, leading to a sector wide call for action. In its report from the conference, the Global Off Grid Lighting Association’s laid out several next steps. These included: a continued commitment to formal and regulated recycling processes; the building of links between repair and recycling activities and the development of an understanding that ‘waste has a value’ [33: p. 10].

Against this backdrop, in March 2016, the UK’s Department for International Development (DFID) commissioned an independent consultancy firm to carry out an analysis of e-waste impacts and mitigation options in off-grid renewable energy markets, focusing on 14 countries in Sub Saharan Africa. The terms of reference acknowledged the need to address the likely scale and impacts of electronic waste (“e-waste”), including battery waste from off grid energy systems, as the household solar sector expands. As the first quantitative analysis of electronic waste from off-grid renewable energy in Africa, the report’s findings and policy recommendations promised to reorient current debate about solar waste in energy transitions across the continent. As the terms of reference outline, the aims of the research were threefold: to ‘inform the definition of e-waste’ amongst policy makers and development partners working to scale up off-grid access to energy; ‘sensitize policy makers to the potential e-waste impacts arising from off-grid technologies’; and ‘to help industry representatives to engage in discussion with their

⁴ Such formal position statements require a vote by GOGLA members with a majority (66%) approval and by its board of directors.

⁵ See: GOGLA [30] ‘End of Life Solar Lamps Recycling Strategy Definition, Kenya and Cameroon (2014) <https://www.gogla.org/resources/end-of-life-solar-lamps-recycling-strategy-definition-kenya-cameroon>.

³ See Byrne [62] for a thorough history of the sector.

authorities by providing them with quality arguments and background data.’

As we explore below, this report introduced new kinds of waste management expertise, concepts and paradigms into the solar industry. These introduced new methodologies for the calculation of waste, new ways of imagining and envisioning waste, and new solutions focused on the idea of ‘Extended Producer Responsibility’ (that hinges on producers or manufacturers making a financial contribution to cover the collection and recycling of products at the end-of-life). Drawing on qualitative approaches to the study of waste and discursive analyses of waste talk in sociology, anthropology, and geography – or what we refer to here as ‘discard studies’ [34] – we reflect on these methods, data, and solutions. The DFID report is important because it is shaping an emerging consensus in the solar industry around what constitutes waste and what are appropriate solutions. But, as we show, this emerging consensus displaces ‘alternative waste management practices and skills’ and pushes them to the ‘margins’ [6, 564].

3.1. Waste management expertise

DFID’s call for tenders was won by a European-based consultancy firm, Cyrcle, which narrowed DFID’s 14 priority countries down to three case study countries, Nigeria, Kenya, and Rwanda; basing their selection on countries with advanced legislation around electronic waste and their personal contacts with in-country researchers. They worked to an eight-week deadline, with a first draft due after the first month.

Cyrcle brought specialist, waste management expertise to questions of electronic waste in the solar industry. Their analysis hinged on a bespoke ‘simulation’ tool – built in Excel – that allowed them to calculate past waste flows and build scenarios for future waste flows. There are different methodologies available for waste management specialists to build such a tool and the Cyrcle specialists used a ‘sales-lifespan’ projection, which allowed them to calculate the volume of future electronic waste from the solar industry based on sales of individual solar units. The simulation tool combined stakeholder interviews with past and projected sales data for off-grid solar products supplied by DFID, as well average life spans for solar products.

As the report’s lead author, Federico Magalini, explained to us in an interview, the report’s methodology and findings were partially defined by the available resources and timetable. ‘We tried to get the best out of the data and the timescale,’ he said. However, the paucity of available data on materials, consumer behaviour and weight coupled with the short timeframe had a material effect on their calculations, shaped their estimates of current and future electronic waste flows in specific ways.

In calculating future waste flows, the authors used a probability model – a Weibull curve – to plot the likely frequency of product disposals over time. In constructing this curve waste management specialist need data on consumer behaviour. They do not usually use the average product lifetimes reported by solar manufacturers; as these are regarded as little more than indicators of ‘technical reliability’. Instead usual practice is to construct the curve on the basis of surveys and interviews with consumers. Questions such as ‘when did you buy your product’ and ‘is it still working?’ are used to collect a quantitative data set on ‘reported disposal practices’. The time constraints in completing the DFID funded report, however, meant that the authors were unable to conduct extensive studies. As Federico explained, ‘We didn’t have any data to create the curve.’ Instead they combined the product lifetimes provided reported by manufacturers with a series of field interviews conducted in Okigwe, Nigeria, and used this to derive an average product life of 3 years.

In their calculations, the authors of the report also needed data on weight. As Federico put it, ‘when it comes to waste people use weight.’ Yet whilst GOGRA, its members and bilateral development partners have begun to carefully record sales figures they do not keep figures on weight. ‘Weight is something that sooner or later this industry will have

to start tracing,’ Federico said. ‘Right now, we have unit sales but we have no idea what their relative weights might be.’ Weights are important in e-waste management because prices are not calculated per unit, as for functioning solar products, but per kg of material.

As a workaround, the report’s authors based their projections on what they called ‘representative weights’. They used industry averages and the detailed technical specifications provided by one or two companies to establish the representative weight of solar products at the point of sale. They did so across seven categories, from a simple solar device with a single light source and a mobile phone charger, 225 g per device, to a large solar home system capable of powering multiple lights, phone charging, fans and televisions, 2.5 kg per device [3: p. 2]. Yet the actual weights of such products on the market vary considerably. Following its publication, Federico conducted stakeholder meetings with off grid solar companies in Nairobi and Kigali. Some companies reported that the average weights of their solar products were much higher than the averages they had used.

Reflecting on these limitations, Federico acknowledged that the original report’s projected estimates of future electronic waste volumes from the solar industry (3600 t in 2017; [3: p. 27]) now appeared conservative. ‘You have less or more waste, depending on how you change the weight values,’ he explained. ‘If the weight is now higher, the impact of off grid would be higher. It is definitely more than 0.5%.’

The messages in reports like this one can change as the circulate globally. E-waste statistics are not ‘immutable mobiles’, things that are stable regardless of their location [35]. On the contrary reports like this one, and the numbers they contain (e.g. 0.3% of total e-waste), can be re-interpreted and re-represented as they move and the subtlety intended by the original authors can be lost as they are downloaded, read and cited [63].⁶

3.2. “The gap”

A second insight concerns ‘the gap’ between breakdown and disposal [65]. The DFID funded report rested on a simple equivalence between sales units and e-waste volumes. Or, put another way, that what is sold can be traced to that which is disposed; with the moment of sale and the moment of disposal separated only by average lifespan, and the period of use. A well-established tenet of social science writing on waste challenges this equivalence.

A foundational premise of discard studies is the absence of a direct relationship between unit sales and the entry of goods into waste streams: here sales volumes do not equate to volumes of waste. Instead, as discard studies scholars show, such understandings of a direct link between ‘sales’ and ‘disposal’ fail to account for the ‘social lives of things’ [36]: that is the non-linear trajectories or movements that materials and parts take, both when they continue to function as a manufacturer intended and after they are broken.

As Rathje and Murphy [37] demonstrate, for example, the relationship between consumption and disposal is complicated. Parts may be lost or added; lifespans may be shortened or lengthened through acts of repair, reuse, and repurposing; and the component parts of broken things may remain in circulation as they acquire new value for people. Weight can be a poor indication of the actual volumes of electronic waste in circulation, as component or constituent parts live on.

For some social scientists attempts to maintain this clear distinction or ‘gap’ between consumption and waste has a deeper symbolic explanation, consistent with the ways that some people around the world attempt to deal with the dead. As Kevin Hetherington argued, bringing Robert Hertz’s analysis of human burials to bear on the passing of inanimate things, there is much that the sociology of consumption can

⁶ As Josh Lepawsky [63] has shown, for example, the careful nuances of a Basel Action Network report on e-waste were all but lost by the time it was cited in a debate in the US Senate.

learn from attention to the ritual practices that accompany death (Hetherington, 2004). Our approach to ‘dead things’, Hetherington proposed, parallels our approach to dead people: we put them at a representational distance while keeping them physically close, in what some societies call a first burial, before putting them physically distant and representationally close in a second burial. That is to say that we first put a broken electronic in a drawer, out of sight, but close to hand (first burial), before we put it out in a bin but bring it closer in the sense we have now decided on our relationship to it: it is waste. In relation to us, its value has stabilised.

The approach to solar waste taken by industry stakeholders and energy policy makers, skips the first burial by establishing non-functioning products immediately as waste. This jump from breakdown to waste means stepping over Hetherington’s ‘gap’ (Hetherington, 2004) and so foreclosing alternative ways to approach, understand and manage the afterlives of off-grid solar products. Our empirical research from Kenya, set out later in this paper, shows the gap between breakdown and disposal is full of actions and activities that equating non-functionality with waste cannot accommodate. Exploring the gap, this realm of activity in drawers and under beds, allows us to consider alternative responses to solar waste.

3.3. Before (and beyond) recycling

A third insight problematises recycling as an ideal end scenario for waste. The off grid solar industry’s response to the DFID-funded report, that took shape in meetings convened by GOGLA, equated end-of-life management with the retrieval of economic value from waste materials through recycling. If solar waste is the problem, the off grid solar industry had it, recycling is the solution.

But how and why has recycling – as a centralised solar waste management strategy – become the solution to decentralised solar waste? After all, as Samantha MacBride [38] has argued: the emphasis on recycling as a waste management strategy puts the burden of responsibility – and, others might add, guilt [39] – on people at the point of consumption; people that is with very different ‘agency’ than those product distributors, manufacturers, designers, and investors further up the supply chain. Moreover the original report itself emphasised the importance of repair as an end of life management strategy, and the importance of partnerships with small-scale repair shops. Part of the explanation, we suggest, may lie in the nature of off grid energy markets and principals of ‘extended producer responsibility’ that have come to dominate contemporary waste management strategies.

The success of any recycling programme is based on reverse logistics: the problem is collection rather than distribution. Reverse logistics present a fundamental challenge to any waste management system. However, these are deemed particularly acute around electronic waste products where emotional connections to products, the extent of financial investments in products, and perceptions of possible future use hinder return rates [40]. These challenges are further exacerbated by physical geography, transport infrastructure and settlement patterns in off-grid markets across Sub-Saharan Africa. Over the past decade the off-grid solar industry has invested considerable resources in the logistical challenge of distributing goods into off grid markets. The challenges of geographical access are frequently mapped onto demographic categories, with the emergence of ‘last mile’ and ‘hard to reach’ consumers.

Criticism of Africa’s off grid solar businesses from social impact investors [41] and from the industry’s own trade association suggests that these efforts continue to fail [42]. Given the logistical challenges of last mile distribution, the challenges of last, or first, mile collection appear even greater. Moreover, where materials and parts have a low or negative recycling value – as the modest microelectronic components and plastics in small scale solar products do [3: p. 27] – there are few economic incentives for producers to collect them.

Neither are there many legislative imperatives on producers.

Around the world, governments base e-waste legislation upon the principle of ‘extended producer responsibility’ This is, primarily, a financial instrument. Extended producer responsibility requires product manufacturers to pay governments for electronic waste according to the volume of their sales in a given market. As such, it also serves to limit the responsibilities of manufacturers, absolving them from any requirement to introduce waste management principles or strategies into the design process, and from any formal requirement to provide repair instructions, servicing or the availability of spare parts.

The draft e-waste regulations produced by Kenya’s National Environmental Management Authority outlined the extended producer responsibility process: from registration of producers, to licensing of suppliers and the penalties that will be imposed for non-compliance. However, the launch of the supplementary bill was called off at the last minute. Four years later, it was still to pass through the Kenyan parliament. In an interview with Murray, one junior minister in the Ministry of Environment and Natural Resources attributed the slow pace of legislation to the challenges of ‘aligning the interests of some parties’.

Extended Producer Responsibility is the legislative manifestation of an understanding of waste as a measurable entity and recycling as its ultimate end. However, our empirical material from Kenya suggests that the legislative approach will disproportionately affect local repair workers with extra obligations (registration fees and quarterly reporting) and the threat of penalties (up to 36 months in prison or 2 million shilling fine) if not operating accordingly. In the draft of the 2013 legislation for instance, a ‘generator’ is defined as: “any person whose activities or activities under his or her direction produces e-waste or if that person is not known, the person who is in possession or control of that e-waste;” ([66]: p5).

The this definition would transform local repair workers, who receive e-waste daily from their customers, into noticeable ‘generators’ of e-waste. The guidelines stipulate that generators must ensure anything they dispose of goes to a licensed collection centre or treatment facility.

3.4. Remembering repair

The final insight is a consequence of the first and second: linking consumption to waste through recycling glosses over an entire ecosystem of spaces, practices and exchanges, as products are repaired, and as materials are reused, repurposed and recycled. Across Sub-Saharan Africa and South Asia this ecosystem frequently constitutes a form of waste management [43]. The DFID funded report acknowledges the presence of a repair economy but places recycling above repair in a hierarchy of waste management; arguing that things will always become waste even after several repair loops.

The authors of the DFID funded report draw on their experience and expertise to present the management of solar waste in the same mould as all waste from electrical and electronic equipment. The report is based on an approach to global e-waste management called the ‘best of two worlds’ [67]. This approach seeks to technically and logistically integrate the pre-processing of electronic waste with the end-processing of hazardous and complex waste fractions in international state-of-the-art processing facilities. Mapping this approach onto an uneven global geography of waste processing facilities, the authors suggest that domestically generated and imported e-waste could be manually disassembled or ‘pre-processed’ at facilities in the Global South before valuable materials could be exported or re-exported to the Global North for end-processing.

Yet the ‘best of two worlds’ approach actually proves better for part of the world. As Lepawsky et al. [44] show, this approach would benefit recycling businesses in high-income countries, whilst the role or position of low-income countries is limited to the first and lowest-value stages of the recycling process. Such an approach would risk dismantling a repair, reuse, repurposing and recycling ecosystem, replacing existing economies, practices and livelihoods with a formal, and

centralised, recycling system that privileges the resources and infrastructure of the Global North. Lepawsky et al. [44] offer an alternative, what they call ‘ethical electronics repair, reuse, repurposing and recycling’: an approach that seeks to achieve better human and environmental health in e-waste management by embracing and integrating with existing ecosystems.

As we wrote in the introduction. The problem is no longer that waste from solar electrical and electronic products is ignored. Today, the problem is how waste is understood and the waste management solutions being proposed. As a pivotal piece of research, the DFID funded study represents the wholesale application of ideas, norms and strategies that have become an accepted and established part of waste management onto a newly ‘discovered’ solar waste stream. Yet, as the work of discard studies scholars demonstrates, these ideas, norms and strategies are likely to reproduce existing relations of power and inequity.

In the following section of the paper we pursue these three insights – the gap between consumption and disposal, the ubiquity of recycling as an endpoint, and the exclusion of repair economies – further, in reference to empirical research from Kenya. In doing so, we explore the afterlives of solar things in the absence of centralised waste management strategies or centralised recycling facilities. We use this material to show how existing repair ecosystems are better equipped to handle and adapt to the diversity of products and materials produced by the off-grid solar industry than emerging narratives around solar waste allow.

4. When solar things break down

According to a recent survey of solar users in nine counties across Kenya, nearly one fifth of solar products in Kenya stop working within 18 months of purchase. So, what happens to solar-powered things when they stop working? Between 2014 and 2016—in collaboration with three Kenyan research assistants – Murray tracked 730 solar products after they were sold.⁷ Through a longitudinal survey and ethnographic fieldwork, this study moved from rural homes where people keep solar devices even after they cease using them, to the small-town repair clinics where these items are repaired, reused, and repurposed and to the company workshops where these things are replaced, returned, and stored. In this section, we move briefly through each of these locations.

4.1. Solar waste at home

In Kenya, 65% of solar products are kept or left in the home when they stop functioning. The off-grid solar industry invites us approach the home primarily as a site of use; these are, after all, solar *home* systems. In marketing materials, impact reports and research documents, we see products lighting up a child’s book or the face of a mother. But the home is also a store of broken things: when solar things stop working they end up under beds, in drawers, and on top of cabinets. By putting products out of sight people transform the home from a site of use into a site of non-use; and in doing so ‘users’ become ‘non-users’ [45].

Murray’s longitudinal survey tracked the problems that these users/non-users faced in living with their solar products (the sample mainly comprised of two brands of product: d.light and SunKing). The survey revealed what users did when problems arose and products stopped functioning. By contrast with the repair clinic and company workshop, households are well-established sites and units of analysis in the literature surrounding energy transitions in the global south (e.g. [46–48]). But whilst researchers have focused on domestic spaces for cooking or sleeping, where new energy technologies like solar lamps

might be used, there have been no comparable attempts to engage with the everyday domestic spaces, like drawers, cupboards, and boxes, where things are placed when they are out of use.

Kenneth – one of the 262 (non-)users surveyed – lives down an untarmacked road, a kilometre from a small trading centre called Sango in Bungoma County. When Murray arrived there in May 2016, he was met by Kenneth’s eldest son Brian. While Brian prepared the living room, Kenneth and Murray sat on white plastic chairs outside. When Murray was ushered into the living room, Kenneth’s first solar powered lighting device – a 24 month old SunKing Eco – was displayed on the coffee table in the middle of the room. Next to it was a newer model, a SunKing Pro2 and an un-branded solar-powered torch. Above, a third SunKing device was attached to a wooden beam. None of the three SunKing devices were fully functional. Each was originally sold with a separate solar photovoltaic panel but only one of these was in the house, laid out on the coffee table for us to see. Neither Kenneth nor Brian knew where the other panels were and the remaining panel (on the coffee table) no longer worked. The family had now found other sources of power for their ‘solar’ lights. Brian’s brother had attached the one to the ceiling beam and was running it off a car battery, while the other two products were taken every 2–3 days to the family shop in Sango, where they were charged via the mains electricity grid.

Such a scenario was common with many others we spoke to in the survey too. (Non-)users frequently reported parts and whole products as missing, lost or stolen. Responses included statements such as: ‘I really don’t know where it is right now’; ‘the pieces were lost’; or ‘I am not even sure where they are’.

When he is not being visited by white researchers, Kenneth’s solar devices live on top of a cabinet, alongside five kerosene lanterns. He keeps them here for safety; as he puts it, ‘down here [gesturing to the living room] one can easily step on it.’ Like others in the survey, recycling these devices was rarely a consideration. Some people spoke of ‘selling’ or ‘giving’ products to ambulant scrap buyers but many were that scathing of how little it would earn them that they would hold on to it instead.

Unlike Kenneth and Brian, few of these respondents had found ways to power their broken devices. Most were holding on, awaiting further instruction from the sales agent or headteacher who sold them the product in the first place. Even fewer users have, like Kenneth and his family, access to a shop with a grid connection. If they lived around Sango, they are more likely to be customers of Kenneth, and would pay 10 shillings (~\$0.10) to charge their lights in his shop, some distance from their homes.

SunnyMoney, the distributor through which Kenneth bought his light, and so we came to contact him and ask to visit his home, offer a warranty on the products they sell. Kenneth had used this to replace the Eco product once (two months after purchase) so when his replacement failed in 2015, his warranty was already over.

Local workarounds to restore functionality to broken solar devices – home fixes and grid-based charging – rarely featured in discussions of failure or breakdown with 12 of Kenya’s leading off grid solar lighting manufacturers where the emphasis instead is on the small number of returns they experience or the high quality standards they hold their products to. If they do acknowledge them, such workarounds are dismissed. In an interview with Murray, for instance, the senior manager at one company acknowledged such practices, explaining that rural customers would be more likely to take a broken device to ‘someone who acts as a sort of repair guy’, ‘the guy who knows how to put two wires together’ rather than take it to a company representative or retailer in the nearest urban centre. But the manager also dismissed such actions, laughing at the prospect, suggesting that such ‘repair guys’ usually fail in their efforts, leading to disagreements between customers and manufacturers over who is to blame for the product’s breakdown.

⁷ The three Kenyan research assistants (Getrude Akinyi, Juliet Wanjiku, and Lilian Oporo) were originally trained by the UK charity Solar Aid.

4.2. Solar waste in the small town repair centre

The ‘repair guy’ that managers refer to is known to Kenyans as a *fundi* – a Swahili word meaning ‘skilled person’. Murray spent three months as an apprentice to one such *fundi*, Wilson, in Bomet County, approximately 220 km west of Nairobi.

Although the sign above Wilson’s roadside clinic only specifies “TV na radio”, during Murray’s time there he dealt with a wide range of consumer electronics. These included: DVD players, mobile phones, inverters, speakers, hair dryers and torches. In addition to a handful of larger solar panels for what Arne Jacobson [49] has referred to as ‘battery-based systems’ he also watched and assisted in the repair of a dozen smaller, ‘plug-and-play’ solar devices that were brought here for repair.

On 1st February 2016, for example, a woman named Esther brought one of these small solar products, a GD Lite solar home system, into the clinic for repair. She told Wilson that the battery was not charging. Wilson was working on a cathode ray tube (CRT) television at the time. It was about 6pm and, as Wilson normally closed the clinic around 7pm, he told Esther he would work on it the following day. Two days later, Esther returned. Wilson had tested the battery with a multimeter and it seemed to be showing a charge. So, after charging the product from the grid (like Kenneth does in Sango), Wilson told Murray to close up the unit and he give it back to Esther who paid 100 shillings (~\$1) for the service.

The next day, Thursday, Esther came back again with her GD Lite unit. The problem now was that the switch to turn the system on was not working. This time Wilson did the repair while Esther waited at the counter. He used his soldering iron to remove the button switch from the circuit board and his fingers to pry out the plastic piece that covers it, leaving a round hole in the side casing of the unit. The button switch and circle of black plastic were cast to the dusty concrete floor of the clinic where they would be swept out to the roadside the next day. In its place Wilson took two short pieces of wire and soldered them to the circuit board, the wires protruding from the hole where the switch once sat. To turn on her system all Esther now had to do was twist the uncovered ends of two wires together; untwisting them to turn it off. There was no charge for this intervention nor for the wire pieces.

Esther returned a third time, the following day, complaining that the battery was still not charging. After testing it quickly with his multimeter Wilson concluded that all was fine and told Esther it just needed to be charged for longer. This diagnosis was again given to Esther for free.

That Sunday, the only day of the week that the clinic is closed, Murray took a motorbike taxi a kilometre north of the town centre to visit Esther, a mother of two, at home. Sat in her dark living room⁸ with the local language, battery-powered, radio blaring and her two children chasing the family chickens around us, Murray asked Esther to narrate the story of her GD Lite and Wilson the *fundi*. Esther, who runs a small general shop selling soap, sugar and rice amongst other staples, explained how she was given the product by her husband – a security guard in Somalia on one of his rare visits home. She was happy to spend 100 shillings on its repair, as she can earn 30–40 shillings a day charging her neighbours phones with it. She chose Wilson ahead of the three other *mafundi* in Bomet town as he had previously repaired the radio we were listening to and the mobile phone through which she had arranged Murray’s visit.

Approaching e-waste management at the level of legislation or centralised recycling, makes it hard to see the interactions that Murray witnessed in the local repair clinic. While Esther’s experience of coming and going with the product might appear long-winded or inefficient,

⁸ It is not only at night that lights are needed in Kenyan homes; long roofs for rain and shade from the sun allow little light in at the windows. Daytime use is another aspect of the well-studied household context that we feel is not well understood.

her solar device did not come with any warranty (as Kenneth’s had) and the Chinese manufacturer – Ningbo Zhengzheng Electrical Appliance Company – unlike Greenlight Planet, does not have any representation in Kenya. The *fundi* was Esther’s warranty, her guarantee.

Ningbo Zhengzheng Electrical Appliance Company is not a member of GOGILA, nor is its GD Lite range of products certified by the Lighting Global quality assurance programme, which requires a 12-month warranty. Ironically, however, it is the success of the Lighting Global programme that has contributed to the emergence of Ningbo and countless other companies like it. Spending less on marketing and reliant on existing electronics retail supply chains these ‘Chinese’ products are typically cheaper than the those of GOGILA members. Previously known as non-certified, copycat or counterfeit, these generic products such as GD Lite, increasingly referred to as ‘non-affiliate’, represent an estimated 71% of pico-solar sales in 2018 [50: 1].

Scathing of the quality of these non-affiliate products, solar company managers also suggest that there is a lack of technical expertise in Kenya to repair them. Yet Willis Makokha, the Head of the Energy Division at the Kenya Industrial Research Development Institute, sees the institution of the *fundi* quite differently: as an old and established source of technology knowledge:

“You find artisans and technicians dealing with what is called repair work of systems and they repair up to component level. And so when you talk about skill, actually skill is there, skill exists. If you walk around the streets of Nairobi you will find shops all over; breaking TVs apart, putting in new components, and getting the TV working.”

4.3. Solar waste in the company workshop

Finally, Murray’s multi-sited ethnography took him to a series of company offices and workshops in Kenya’s capital city, Nairobi and the port city of Mombasa. In mid-December 2016 Murray spent a day in Sollatek’s workshop on the Nyalali Road that runs north of Mombasa Island. Sollatek have their sales, finance, business, and warehouse teams on the same site as their repairs team. This proximity or overlap between repair and logistics operations was something Murray noticed in the 8 other company workshops he visited. Sollatek deal in charge controllers, solar water heating and large solar systems as well as small scale solar devices. These small solar devices are what, occupy at least one member of Sollatek’s four-strong repair team at any one time.

The day before Murray’s visit a Niwa Home 200 × 2 product had been brought in the day before by a representative from a nearby sisal plantation. Benson, a graduate of the Electrical and Electronic Engineering at the Technical University of Mombasa, was on duty for the small solar products that month (a monthly rota saw the four technicians move through roles in the workshop). He explained to Murray that the solar device was ‘not giving enough lighting hours’.

The first thing Benson did was to check the lights were turning on. They were. The next step was to test the panels. However, the device had been returned without a ‘solar upgrade plug’, a small connector that allowed the Niwa’s solar panels to be connected to each other in a modular fashion. This failure to return a non-functioning device with all of the pieces was something each of the company technicians Murray shadowed encountered regularly, and was also common at Wilson’s repair clinic in Bomet.

Rather than immediately contacting the dealer or looking for a similar connector in the store or in the basement underneath the workshop, Benson dusted the system down. Cleaning, externally with a cloth or rag and internally with paraffin or white spirit were ubiquitous steps in the repair process. Benson took the panels out the back to check the panels with a multi-meter. They appeared to be working and so Benson concluded that the cable connecting them to the battery unit was the problem. So he went to look for a new cable, first in the adjacent company showroom and then downstairs in the basement stockroom. When the replacement cable made no difference, the charging indicator

on the battery unit remaining unlit, Benson re-concluded that the fault might be rust inside the port where these cables connect to the panel. Using the multimeter once again Benson could see that there was current at the base of the metal contacts (nearest the panel) but nothing at the tip (nearest the cable). Benson began to scratch off the rust on the tip of the contacts with the pins of the multimeter, a technique Murray observed across clinics and workshops. When this still did not solve the problem Benson turned his attention to the removal of the frame around the solar panel, so that he could better access, and more thoroughly clean, the metal contacts.

On this occasion, Benson had left his toolbox at home. 'So,' he said, 'I will have to improvise. Today, a flat screwdriver will do.' The Niwa product requires a 'hex' or hexagonal screwdriver to remove the panel frame but Benson borrowed a flat screwdriver from a colleague and used this, at an angle, to unscrew the plastic frame of the panel. Like Wilson the *fundi*, Benson spoke of improvising (using a flat rather than hex screwdriver) with the Swahili prefix 'ku-' (which signifies the infinitive) to create a new verb: *kuimprovise*. Looking at the contact and scratching it some more with the flat screwdriver he saw what he described as 'oxide' that had formed due to 'water ingress'. Benson brushed away dirt and dust from the inside rim of the panel frame with a large paintbrush, and then bashed the frame face down on the bench to knock the rest of the particles out. Benson told Murray he wanted to add some solder to one (the more rusted) contact of the panel to increase its conductivity, but they would do it after lunch.

Over lunch, in a nearby roadside café, Benson revealed that he normally brings his own tools to work because he operates his own repair clinic at evenings and weekends, supplementing his company salary. This side-income was also encountered at other manufacturers and distributors, often facilitated by the mobile money network M-Pesa, which allows small cash transaction to be made directly from customer to technician.

After lunch, Benson applied extra solder to the connectors but discovered that the charging indicator was still not lighting up. He had now worked on this one job for several hours: troubleshooting component after component, and testing new ideas or theories as to what might be the problem. Noticing that none of these steps were being recorded anywhere Murray asked Benson whether he ever needed to write anything down. 'Why should you write it down when you're supposed to repair it,' Benson replied, explaining that you just have to 'troubleshoot' and 'repair' at the same time otherwise you will forget. Defeated and fatigued Benson put the Niwa product on to charge from the grid, once fully charged (the next day) he would conduct a 'drain test': leave the two lights on until the battery was completely drained. Benson conceded that the sisal farmer would likely be given a replacement product.

These three vignettes – of home based repair, small town *fundi* repair, and a company-employed technician repair – offer an insight into a complex ecosystem of reuse, repair and replacement that exists around broken solar products in Kenya. Kenneth's decision to charge his products from the grid – a re-use – transform his solar lantern in to a grid one. Esther's repeated visits to her *fundi* for repair demonstrate a similar patient willingness to adapt her use of the product; twisting and un-twisting wires rather than pressing and un-pressing a button. While, despite Benson's rather lengthy efforts, the replacement of the Niwa Home 200 is the example that produces the most waste – the whole product (as opposed to two pieces of plastic at Wilson's clinic, and one panel at Kenneth's house).

Attempts to introduce formal, bureaucratic and centralised waste management systems in the off-grid solar industry are likely to disrupt and marginalise this existing repair economy. The network of *mafundi* across Kenya demonstrates the alternatives to recycling and provides a safety net for never-guaranteed non-affiliate products as well as beyond-warranty certified ones. Meanwhile our forays into company workshops offer a reminder of the persistence of informal repair practices that do not follow formal technical instructions. The next, and

concluding, section of the paper offers some suggestions for future pathways that might better acknowledge, if not chaperone, the wider transitions and impacts that off-grid solar market is having on repair ecosystems across sub-Saharan Africa.

5. Pathways to unsustainability?

This special issue of Energy Research and Social Science set out to offer 'socio-cultural' insights to counterbalance the hitherto dominance of technology-finance perspectives on sustainable energy access in Sub Saharan Africa. Our contribution has offered a trenchant reminder that the adoption of off-grid solar products in households across sub-Saharan Africa does not just presage a low-carbon energy transition; it also presages new flows of waste from electrical and electronic equipment.

But what happens to small-scale solar technologies when they cease to operate or break down? As governments, international development donors and the off grid solar industry have sought to address emerging challenges around e-waste solar technologies in Sub Saharan Africa a dominant technology-finance answer to this question has emerged. This answer has focused on the production and measurement of e-waste, and has led to a set of policy recommendations and pathways for action focused on centralised take back and recycling schemes.

As we have shown in this paper, a different but equally important answer to this question is that broken solar powered things do not immediately become electrical or electronic 'waste'. On the contrary, when off-grid solar products stop working they reveal the range of social, cultural and economic activity around disposal, storage, retrieval, repair, and reworking. Breakdowns, as countless social studies of waste remind us, make things visible [51].

In this paper we set out to challenge an emerging consensus on solar waste in Sub Saharan Africa. First, on its own terms, by questioning current methodologies for estimating volumes. Second, because an emerging consensus equates the 'end of life' with waste. Third, because this emerging consensus is establishing and entrenching a specific set of solutions.

These solutions – in common with approaches to 'extended producer responsibility' across other electronic industries and sectors – shift responsibilities away from production and manufacture. They create few incentives for off grid solar manufacturers to rethink the design of off grid products, to reduce or eliminate the use of un-recyclable plastics, or to extend the working life of products by designing for reparability. These solutions render invisible the broader ecosystem of repair and maintenance work, in which productive repurposing and re-use is an important part of livelihoods. Instead, they focus industry attention on centralised or centrally managed take back schemes, collection strategies and recycling infrastructures. Yet little, if any, of this infrastructure currently exists, as the DFID-funded report itself recognises [3: p. 35].

The perspectives and empirical data presented in this paper have offered alternative ways for conceptualising solar waste and pathways for action. As we have shown, in Kenya the parts and components of broken solar systems retain a potential use value for users and repair workers. Rather than emphasise broken devices as 'problems' to be managed we have sought to reflect on the ways that parts and components are used and re-used. In Kenya broken solar systems join an entire world of broken consumer goods, for which there are existing networks, practices and responses. These networks, practices and responses have accommodated or are adapting to the off grid solar industry; absorbing new materials and component parts.

What can energy research and energy practice learn from the afterlives of solar power in Kenya? In this paper we have shown that the off grid solar industry demands to be subjected to the same scrutiny as other industries, with the aim of supporting a more just or equitable solar economy. As we showed, ideas of energy justice are central to the claims and activities of the off grid solar industry. Indeed, the very challenge of accelerating access to energy is a question of distribution,

albeit one that is framed by the market. Yet the burgeoning scholarship on energy justice has yet to fully engage with what happens when renewable energy products reach the apparent end of their working lives.

Energy justice is not just the distribution of access to energy (and appliances). But also, we propose, about waste and repair, about access to materials and parts, and access to designs and knowledge. We must look at distribution of risks and harms that comes with expanding energy access – where are they? And who faces them? Energy justice needs to be about procedural justice too. Rather than focus on absent or non-existent recycling facilities, we argue that sustainable pathways to energy access in Sub Saharan Africa hinge on the willingness of the solar industry to acknowledge and engage with an existent, vibrant and diverse repair economy. If Africa's renewable energy transitions are to be socially and environmentally sustainable, we argue, the off grid solar industry must make new commitments to sustainable design and work to ensure the last mile distribution of replacement parts and sub-components as well as products. Many of the questions we raise here might also be asked of the cookstoves, smart energy meters, or solar-powered water pumps.

The World Bank/International Finance Corporation's Lighting Global certification programme requires that companies seeking its approval for their products must provide a twelve-month consumer warranty [50: p. 1]. However, these warranties, existing after-sales services in the off-grid solar industry do little to attend to the physical temporality and longevity of component parts, plastics and metals which materially outlast 12 months by orders of magnitude. Nor do they account for products being re-sold, given as gifts, travelling to different regions and countries, or being separated from the packaging where warranty information is often displayed.

Some off-grid solar businesses have sought to address concerns from their distributors and end-users, and remain competitive in an increasingly crowded market place, by offering even more extensive replacement and take-back schemes for their products. Such schemes bracket corporate responsibility by establishing a company's commitment to replace or repair objects only where they have not been opened, within a fixed period of time from the moment of sale, and by placing the burden of responsibility for returning the item to the vendor on the consumer. As we explored in this paper, these interventions fail to acknowledge the range of activities that take place when products stop working or functioning, as people work to restore varying degrees of functionality through repair.

If the off grid solar industry is producing new flows of electronic waste it is because waste is built into solar products by design. In our interviews, people working for GOGLA affiliated solar manufacturing companies frequently accuse non-affiliated, Chinese solar manufacturers of selling pico-solar products that are 'made to break', with short life product times the result of sub-standard components and manufacturing processes, intended to ensure frequent re-purchases. But "planned obsolescence" is not only a deliberate process, it can also be the unintended outcome of design decisions that determine how components are assembled and whether the components are available individually, in-market.

In our interviews and at industry gatherings the managers of Lighting Global certified companies describe the work of manufacturing as a struggle to balance costs or affordability against minimum product standards, and point to the 1 or 2 year warranties on their products as offering consumers' protection against failure and breakdown. Yet by making consumer warranties a central component of product standards the Lighting Global quality assurance programme has also encouraged and promoted the black boxing of technology. For consumer warranties to be honoured, devices must be tamper proof; and tamper proof solar products are not easily repairable products. Some of the most high profile and successful off grid solar manufacturing companies may meet minimum Lighting Global product standards but their choice of battery, the location of batteries inside closed plastic casings, and the choice of screws and fittings has material consequences for anybody who seeks to

keep something in use beyond its product warranty by maintaining or repairing it.

Understanding the off grid solar economy in Sub Saharan Africa necessitates attention to social behaviour – wants and needs, desires and aspirations – that shape how and why people acquire or adopt solar technologies, and what they do with them when they operate. Increasingly, it will also require attention to the practices and activities around solar technologies when they no longer operate as intended. Such insights are vital if we are to address emerging global electronic waste challenges and the possibility of just transitions to a low carbon future.

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